Chapter 14: Waves and Energy Transfer

Practice Problems

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1. A sound wave produced by a clock chime 515 m away is heard 1.50 seconds later.

   a. What is the speed of sound in air?

   $$v = \frac{d}{t} = \frac{(515\text{ m})}{(1.5\text{ s})} = 343\text{ m/s}$$

   b. The sound wave has a frequency of 436 Hz. What is its period?

   $$T = \frac{1}{f} = \frac{1}{(436\text{ Hz})} = 2.29 \times 10^{-3}\text{ s}$$
   $$= 2.29\text{ ms}$$

   c. What is its wavelength?

   $$\lambda = \frac{v}{f} = \frac{(343\text{ m/s})}{(436\text{ Hz})} = 0.787\text{ m}$$

2. A hiker shouts toward a vertical cliff 685 m away. The echo is heard 4.00 s later.

   a. What is the speed of sound in air?

   $$v = \frac{d}{t} = \frac{(685\text{ m})}{(2.0\text{ s})} = 343\text{ m/s}$$

   b. The wavelength of the sound is 0.75 m. What is its frequency?

   $$f = \frac{v}{\lambda} = \frac{(342\text{ m/s})}{(0.750\text{ m})} = 457\text{ Hz}$$

   c. What is the period of the wave?

   $$T = \frac{1}{f} = \frac{1}{(456\text{ Hz})} = 2.19 \times 10^{-3}\text{ s}$$
   $$= 2.19\text{ ms}$$

3. A radio wave (a form of electromagnetic wave) has a frequency of 99.5 MHz (99.5×10^6 Hz). What is its wavelength?

   $$\lambda = \frac{v}{f} = \frac{(3.00 \times 10^8\text{ m/s})}{(99.5 \times 10^6\text{ Hz})}$$
   $$= 3.02\text{ m}$$

Practice Problem

4. A typical light wave has a wavelength of 580 nm.

   a. What is the wavelength of the light in meters?

   $$\lambda = (580\text{ nm})(1 \times 10^{-9}\text{ m/nm})$$
   $$= 5.8 \times 10^{-7}\text{ m}$$

   b. What is the frequency of the wave?

   $$f = \frac{v}{\lambda} = \frac{(3.0 \times 10^8\text{ m/s})}{(5.8 \times 10^{-7}\text{ m})}$$
   $$= 5.2 \times 10^{14}\text{ Hz}$$

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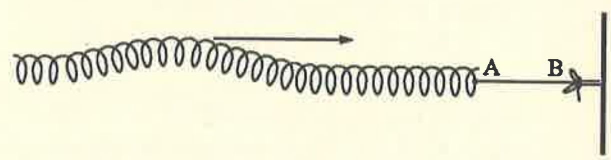
5. A pulse is sent along a spring. The spring is attached to a light thread that is tied to the wall, as in Figure 14–12.



   a. What happens when the pulse reaches point *A*?

   The pulse is partially reflected, partially transmitted.

   b. Is the pulse reflected from *A* erect or inverted?

   Erect, since reflection is from a less dense medium.

   c. What happens when the transmitted pulse reaches *B*?

   It is almost totally reflected from the wall.

   d. Is the pulse reflected from *B* erect or inverted?

   Inverted, since reflection is from a more dense medium.

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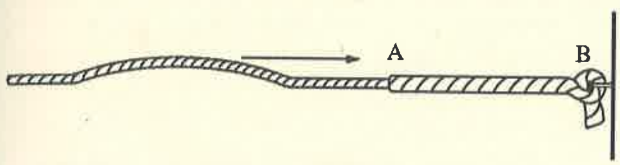
6. A long spring runs across the floor of a room and out the door. A pulse is sent along the spring. After a few seconds, an inverted pulse returns. Is the spring attached to the wall in the next room or is it lying loose on the floor?

   Pulse inversion means rigid boundary; attached to wall.

7. If you want to increase the wavelength of waves in a rope, should you shake it at a higher or lower frequency?

   At a lower frequency because wavelength varies inversely with frequency.

8. A pulse is sent along a thin rope that is attached to a thick rope. The thick rope is itself tied to a wall, as in Figure 14–14.



   a. What happens when the pulse reaches point *A*?

   The pulse is partially reflected, partially transmitted.

   b. Is the pulse reflected from *A* erect or inverted?

   Inverted, since reflection is from a more dense medium.

   c. What happens when the transmitted pulse reaches *B*?

   It is almost totally reflected from the wall.

   d. Is the pulse reflected from *B* erect or inverted?

   Inverted, since reflection is from a more dense medium.

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1. The Sears Building in Chicago sways back and forth with a frequency of about 0.10 Hz. What is its period of vibration?

$$T = \frac{1}{f} = \frac{1}{(0.10\text{ Hz})} = 10\text{ s}$$

2. An ocean wave has a length of 10.0 m. A wave passes a fixed location every 2.0 s. What is the speed of the wave?

$$v = f\lambda = \frac{1}{2.0\text{ s}}(10.0\text{ m}) = 5.0\text{ m/s}$$

3. Water waves in a shallow dish are 6.0 cm long. At one point, the water oscillates up and down at a rate of 4.8 oscillations per second.

   a. What is the speed of the water waves?

$$v = f\lambda = (4.8\text{ Hz})(6.0\text{ cm}) = 29\text{ cm/s}$$

   b. What is the period of the water waves?

$$T = \frac{1}{f} = \frac{1}{(4.8\text{ Hz})} = 0.21\text{ s}$$

4. Water waves in a lake travels 4.4 m in 1.8 s. The period of oscillation is 1.2 s.

   a. What is the speed of the water waves?

$$v = \frac{d}{t} = \frac{(4.4\text{ m})}{(1.8\text{ s})} = 2.4\text{ m/s}$$

   b. What is their wavelength?

$$\lambda = \frac{v}{f} = vT = (2.4\text{ m/s})(1.2\text{ s})$$
$$= 2.9\text{ m}$$

5. The frequency of yellow light is 5.0×10^{14} Hz. Find its wavelength.

$$\lambda = \frac{c}{f} = \frac{(3.00 \times 10^8\text{ m/s})}{(5.0 \times 10^{14}\text{ Hz})}$$
$$= 6.0 \times 10^{-7}\text{ m}$$

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6. A group of swimmers is resting in the sun on an off-shore raft. They estimate that 3.0 meters separate a trough and an adjacent crest of surface waves on the lake. They count 14 crests that pass by the raft in 20 seconds. How fast are the waves moving?

$\lambda = 2(3.0 \text{ m}) = 6.0 \text{ m}$,

$f = \frac{(14 \text{ waves})}{(20 \text{ s})}$

$= 0.70 \text{ Hz}$

$v = f\lambda = (0.70 \text{ Hz})(6.0 \text{ m})$

$= 4.2 \text{ m/s}$

7. AM radio signals are broadcast at frequencies between 550 kHz and 1600 kHz (kilohertz) and travel 3.0×10^8 m/s.

a. What is the range of wavelengths for these signals?

$v = f\lambda$

$\lambda = \frac{v}{f} = \frac{3.0 \times 10^8 \text{ m/s}}{5.5 \times 10^5 \text{ Hz}}$

$= 550 \text{ m}$

$\lambda = \frac{v}{f} = \frac{3.0 \times 10^8 \text{ m/s}}{1.6 \times 10^6 \text{ Hz}}$

$= 190 \text{ m}$

b. FM frequencies range between 88 MHz and 108 MHz (megahertz) and travel at the same speed. What is the range of FM wavelengths?

$\lambda = \frac{v}{f} = \frac{3.0 \times 10^8 \text{ m/s}}{8.8 \times 10^7 \text{ Hz}}$

$= 3.4 \text{ m}$

$\lambda = \frac{v}{f} = \frac{3.0 \times 10^8 \text{ m/s}}{1.08 \times 10^8 \text{ Hz}}$

$= 2.8 \text{ m}$

8. A sonar signal of frequency 1.00×10^6 Hz has a wavelength of 1.50 mm in water.

a. What is the speed of the signal in water?

$v = f\lambda = (1.00 \times 10^6 \text{ Hz})(1.50 \times 10^{-3} \text{ m})$

$= 1.50 \times 10^3 \text{ m/s}$

b. What is its period in water?

$T = \frac{1}{f} = \frac{1}{1.00 \times 10^6 \text{ Hz}} = 1.00 \times 10^{-6} \text{ s}$

c. What is its period in air?

$T = 1.00 \times 10^{-6}$ s. The period and frequency remain unchanged.

9. A sound wave of wavelength 0.70 m and velocity 330 m/s is produced for 0.50 s.

a. What is the frequency of the wave?

$v = f\lambda$, so $f = \frac{v}{\lambda} = \frac{(330 \text{ m/s})}{(0.70 \text{ m})}$

$= 470 \text{ Hz}$

b. How many complete waves are emitted in this time interval?

$ft = (470 \text{ Hz})(0.50 \text{ s})$

$= 240$ complete waves

c. After 0.50 s, how far is the front wave from the source of the sound?

$d = vt$

$= (330 \text{ m/s})(0.50 \text{ s})$

$= 170 \text{ m}$

10. The speed of sound in water is 1498 m/s. A sonar signal is sent from a ship at a point just below the water surface and 1.80 s later the reflected signal is detected. How deep is the ocean beneath the ship?

The time for the wave to travel down and back up is 1.80 s. The time one way is half 1.80 s or 0.900 s.

$d = vt = (1498 \text{ m/s})(0.900 \text{ s}) = 1350 \text{ m}$

11. The velocity of the transverse waves produced by an earthquake is 8.9 km/s, while that of the longitudinal waves is 5.1 km/s. A seismograph records the arrival of the transverse waves 73 seconds before that of the longitudinal waves. How far away was the earthquake?

$d = vt$. We don't know t, only the difference in time Δt. The transverse distance, $d_T = v_T t$, is the same as the longitudinal distance, $d_L = V_L(t + \Delta t)$. Use $v_T t = v_L(t + \Delta t)$, solving for $t = v_L \Delta t/(v_T - v_L) = 98$ s. Then, $d = v_T t = (8.9 \text{ km/s})(98 \text{ s}) = 8.7 \times 10^2$ km.

12. The velocity of a wave on a string depends on how hard the string is stretched, and the mass per unit length of the string. If T is the force exerted on the string, and μ is the mass/unit length, then the velocity, v, is

$$v = \sqrt{\frac{T}{\mu}}.$$

A piece of string 5.30 m long has a mass of 15.0 g. What must the tension in the string be to make a wavelength of a 125 Hz wave 120.0 cm?

$v = f\lambda = (125\ \text{Hz})(1.200\ \text{m}) = 150\ \text{m/s}$, and

$$\mu = \frac{m}{\ell} = \frac{1.50 \times 10^{-2}\ \text{kg}}{5.30\ \text{m}} = 2.83 \times 10^{-3}\ \text{kg/m}.$$

Now $v = \sqrt{\frac{T}{\mu}}$, so

$$T = v^2\mu = (150\ \text{m/s})^2(2.83 \times 10^{-3}\ \text{kg/m}) = 63.7\ \text{N}$$

13. The time needed for a water wave to change from the equilibrium level to the crest is 0.18 s.

a. What fraction of a wave length is this?

$\frac{1}{4}$ wavelength

b. What is the period of the wave?

$T = 4(0.18\ \text{s}) = 0.72\ \text{s}$

c. What is the frequency of the wave?

$$f = \frac{1}{T} = \frac{1}{(0.72\ \text{s})} = 1.4\ \text{Hz}$$

14. The wave speed in a guitar string is 265 m/s. The length of the string is 63 m. You pluck the center of the string by pulling it up and letting go. Pulses move in both directions and are reflected off the ends of the string.

a. How long does it take for the pulse to move to the string end and return to the center?

$d = 2(63\ \text{cm})/2 = 63\ \text{cm}$, so

$$t = \frac{d}{v} = \frac{(0.63\ \text{m})}{(265\ \text{m/s})} = 2.4 \times 10^{-3}\ \text{s}.$$

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b. When the pulses return, is the string above or below its resting location?

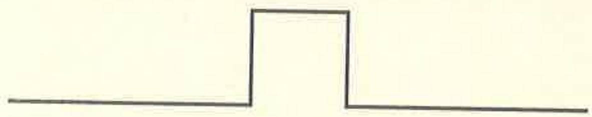
Pulses are inverted when reflected, so returning pulse is down (below).

c. If you plucked the string 15 cm from one end of the string, where would the two pulses meet?

15 cm from the other end, where the distances travelled are the same.

15. Sketch what happens, for each of the three cases shown in Figure 14–23, when centers of the two wave pulses lie on the dashed line so the pulses exactly overlap.

a. The amplitude is doubled.



b. The amplitudes cancel each other.

c. If the amplitude of the first pulse is $\frac{1}{2}$ of the second, the resultant pulse is $\frac{1}{2}$ of the second.

16. If you slosh the water back and forth in a bathtub at the correct frequency, the water rises first at one end and then at the other. Suppose you can make a standing wave in a 150–cm long tub with a frequency of 0.30 Hz. What is the velocity of the water wave?

$d = 3.0\ \text{m}$, $t = \frac{1}{(0.30\ \text{Hz})}$

$v = \frac{d}{t} = (3.0\ \text{m})(0.30\ \text{Hz}) = 0.90\ \text{m/s}$

1. A periodic transverse wave that has a frequency of 10.0 Hz travels along a string. The distance between a crest and either adjacent trough is 2.50 m. What is its wavelength?

   The wavelength is the distance between adjacent crests, or twice the distance between a crest and an adjacent trough.
   $\lambda = 2(2.50 \text{ m}) = 5.00 \text{ m}$

2. A wave generator produces 16.0 pulses in 4.00 s.

   a. What is its period?

   $\frac{(4.00 \text{ s})}{(16.0 \text{ pulses})} = 0.250$ s/pulse, so

   $T = 0.250$ s

   b. What is its frequency?

   $f = \frac{1}{T} = \frac{1}{(0.250 \text{ s})} = 4.00 \text{ Hz}$

3. A wave generator produces 22.5 pulses in 5.50 s.

   a. What is its period?

   $\frac{(5.50 \text{ s})}{(22.5 \text{ pulses})} = 0.244$ s/pulse, so

   $T = 0.244$ s

   b. What is its frequency?

   $f = \frac{1}{T} = \frac{1}{(0.244 \text{ s})} = 4.10 \text{ Hz}$

4. What is the speed of a periodic wave disturbance that has a frequency of 2.50 Hz and a wavelength of 0.600 m?

   $v = \lambda f = (0.600 \text{ m})(2.50 \text{ Hz}) = 1.50 \text{ m/s}$

5. One pulse is generated every 0.100 s in a tank of water. What is the speed of propagation of the wave if the wavelength of the surface wave is 3.30 cm?

   $v = \frac{\lambda}{T} = \frac{(3.30 \text{ cm})}{(0.100 \text{ s})} = 33.0 \text{ cm/s} = 0.330 \text{ m/s}$

6. Five pulses are generated every 0.100 s in a tank of water. What is the speed of propagation of the wave if the wavelength of the surface wave is 1.20 cm?

   $\frac{(0.100 \text{ s})}{(5 \text{ pulses})} = 0.0200$ s/pulse, so $T = 0.0200$ s.

   $v = \frac{\lambda}{T} = \frac{(1.20 \text{ cm})}{(0.0200 \text{ s})} = 60.0 \text{ cm/s} = 0.600 \text{ m/s}$

7. A periodic longitudinal wave that has a frequency of 20.0 Hz travels along a coil spring. If the distance between successive compressions is 0.400 m, what is the speed of the wave?

   $v = \lambda f = (0.400 \text{ m})(20.0 \text{ Hz}) = 8.00 \text{ m/s}$

8. What is the wavelength of a water wave that has a frequency of 2.50 Hz and a speed of 4.0 m/s?

   $\lambda = \frac{v}{f} = \frac{(4.0 \text{ m/s})}{(2.50 \text{ Hz})} = 1.6 \text{ m}$

9. The speed of a transverse wave in a string is 15.0 m/s. If a source produces a disturbance that has a frequency of 5.00 Hz, what is its wavelength?

   $\lambda = \frac{v}{f} = \frac{(15.0 \text{ m/s})}{(5.00 \text{ Hz})} = 3.00 \text{ m}$

10. The speed of a transverse wave in a string is 15.0 m/s. If a source produces a disturbance that has a wavelength of 1.25 m, what is the frequency of the wave?

    $f = \frac{v}{\lambda} = \frac{(15.0 \text{ m/s})}{(1.25 \text{ m})} = 12.0 \text{ Hz}$

11. A wave has an angle of incidence of 24°. What is the angle of reflection?

    The angle of incidence is equal to the angle of reflection; thus, both are 24°.